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Genetics and Genomics of Aroma of Rice and Its Quality Enhancement Parameters: A Review

Usama Waheed [a*], Zia Ur Rehman [a], Hassan Raza [a], Muhammad Abdullah Faisal [a], Eisha-Tul-Razia [a], Tazeen Zohra [a], Muhammad Naveed [a] and Sadaf Batool [a]

[a] *Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Rice or The (*Oryza sativa* L), is a crucial cereal crop because it provides essential vitamins to more than 50% of the world's population. Almost 90% of the world's rice output is produced in Asia, particularly South Asia, where its cultivation is predominantly focused. People from different regions of the world have varying tastes in rice. The scent is influenced by more than 500 volatile chemical components. The most crucial for rice flavors among them has been found as 2 acetyl-1-pyrroline (2AP). It is observed that the fragrance characteristic is correlated with three quantitative trait loci (QTLs). The most important QTL for fragrance is called Qaro8.1, and it is located on chromosome 8. The identification of QTLs in the genome uses a variety of markers, including molecular markers and DNA markers.

**Corresponding author: E-mail: usama.uaf.pbg@gmail.com;*

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1. INTRODUCTION

Rice, which comes from the plant genus *Oryza sativa L*.is an essential source of vitamins and proteins that contribute to proper nutrition for more than half of the world's population. This multipurpose crop has a high concentration of a wide variety of minerals, including thiamine, riboflavin, niacin, vitamin E, zinc, potassium, and iron. [1]. In East African marketplaces, the predominant aspect that motivates purchasers is the aroma, even though consumers' preferences about the quality of the grain are a matter of personal taste. Hence, rice farmers all over the globe who plant aromatic rice varieties may gain large profits from the unique scent of their products because aromatic rice types have a higher demand [2]. More than half of the world's population eats rice as a staple diet, making it the most significant cereal crop [3]. Genetic factors influence rice fragrance, but environmental factors also play a part. Asia, especially South Asia, is the region where rice is grown for over 90% of the world's rice production. Both biotic and abiotic factors can affect rice production, although drought stress is the main one that affects rain-fed areas [4]. Additionally, due to drought, climate change has a negative association with rice output. Consequently, it is essential to cultivate drought-tolerant cultivars. In the majority of Asian nations. Six of the 27 species in the *Oryza* genus have diploid genomes (n = 12: AA, BB, CC, EE, FF, and GG), while five have polyploid genomes (n = 24: BBCC, CCDD, HHJJ, HHKK, and KKLL). Rice is divided into aromatic and non-aromatic varieties based on whether an aroma is present [5]. Non-aromatic rice varieties are typically developed in all nations that cultivate rice and are high yielding, show strong agronomic performance, and are highly adaptable to environmental conditions. Contrarily, the majority of aromatic rice genotypes are produced, have low yields, poor agronomic performance, and are very susceptible to environmental conditions [6]. Fragrant rice is widely praised for its outstanding scent and superior grain quality despite its subpar performance [7]. According to a phylogenetic study, the aroma genes are derived from the wild cousins *(Oryza nivara and O. rufipogon),* with the Indian subcontinent serving as their primary origin from where they spread to other areas of the world [8]. Natural selection played a major role in the evolution of aromatic rice varieties over thousands of years. Local farmers then continued this process by selecting varieties that suited their preferred cultivation methods. Finally, plant breeders continued this process over time by making improvements [9]. As a result, it is possible to view the scent of rice as a natural occurrence that has been supported and maintained by the selection process.

1.1 Preferences of Rice Consumers and the Aroma of Rice

1.1.1 The preference of rice consumers

People from many regions of the world have varying tastes in rice. Regardless of the physical and chemical properties of rice, low-income individuals prefer inexpensive rice to Basmati in general [8]. However, Muhammad's research in Indonesia shows that wealthy people prefer rice with a nice flavor [10]. Due to the fragrance, rice prices are raised. The Ugandan population prefers rice that is white in color, whole-grained, and aromatic. Rwandan urban residents, however, prefer long-grained, fragrant rice. Tanzanian consumers like eating the nation's flavorful indigenous rice [8]. Additionally, rural residents and employers of police and military personnel consume rice of the lowest possible quality [11]. Consumers in Western nations preferred rice with a fluffy texture and a softer scent, but those in Asian countries liked rice with a sticky texture and a strong perfume. Overall, research indicates that a range of elements, such as flavor, texture, scent, and cooking timing, affect customer preferences for rice. Producers and marketers of rice may better match the demands and expectations of their target customers by being aware of these preferences [12].

1.2 Aroma of Rice

Civilization throughout the world places a great emphasis on rice scent as an essential quality. When rice is cooked, a variety of volatile organic compounds (VOCs) are emitted, giving rice its distinctive scent. Aldehydes, ketones, alcohols, esters, and other substances are among these VOCs. The type of rice, the way it is cooked, and the place where it is farmed can all affect the distinctive scent of the grain. For instance, basmati rice has a nutty and fragrant scent, whilst jasmine rice is renowned for its sweet and flowery perfume. The scent of rice affects its perceived quality and nutritional worth in addition to its sensory appeal. According to studies, individuals frequently believe that rice with a strong scent is of a higher caliber and has more nutrients. Overall, many people all around the world appreciate and like rice's scent, which is a significant component of its total sensory experience. Rice is priced based on its scent in both domestic and foreign markets. More than 500 volatile chemical molecules, for example, impact the scent of rice, among other things [13]. The most crucial for rice flavoring among them has been discovered as 2 acetyl-1-pyrroline (2AP) [14,15]. 2AP is an aromatic chemical that some researchers have also called 2-AcPy or 2-ACP. 2-AP is known by its IUPAC designation, 5-acetyl-3, 4-dihydro-2H-pyrrole. The content of 2AP in rice may be separated and quantified using a variety of techniques, but the most practical method is gas chromatography combined with mass spectrometry, which is also the most expensive and time-consuming. As a result, there are several ways to assess rice's scent. Generally speaking, the scent may be measured by either boiling the kernel or vegetative component and then sniffing the cooked kernel for aroma [10,16] or by testing the flavor by biting between the teeth [15] [8] [17]. Rice breeders employ a quicker method that Sood and Siddiq devised for assessing rice smell [18]. This states that any segment of the rice plant, except roots, can be treated with 0.1 M potassium hydroxide for 10–12 minutes before a panel of sensory specialists trained in rice fragrance assessment evaluates the emitted scent. Because each person's sensitivity to rice smell differs, a panel of specialists is required. This is currently accepted as a fundamental method for the sensory evaluation of scent on a global scale. Different factors, such as variations in rice varieties and environmental factors, might affect 2AP content [19].

2. GENETIC BASIS OF AROMATIC RICE

The scent of rice is thought to be controlled by a single recessive gene at first, but further research by scientists showed that this attribute may also be controlled by a dominant gene or additional genes [20] [21] [22]. On chromosomes 4, 8, and 12, several rice aroma QTLs have been found, whereas, in Pusa 1121, at least three QTLs have been found on chromosomes 3, 4, and 8 [23]. It has been shown that the fragrance characteristic is correlated with three quantitative trait loci (QTLs). The most important QTL for fragrance is Qaro8.1, which is situated on chromosome 8 [24]. This characteristic has been linked to another important QTL on chromosome 3 called qaro3-1 [25]. Additionally, several alleles of the badh1 gene, which is a part of the QTL qaro4.1 on chromosome 4, have been linked to fragrance in rice cultivars [8, 10]. It is interesting to note that non-aromatic genotypes of rice have homozygous forms of the main gene responsible for scent. According to research, the main factor influencing rice scent is a non-functional variation of the badh2 gene, which produces the betaine aldehyde dehydrogenase enzyme. Certain rice genotypes lack smell due to the existence of a functioning allele of the badh2 gene. There are currently 19 alleles connected to the badh2 gene that has been identified as influencing rice aroma. The badh2-E7 variation of these alleles was discovered to be the one that was present in the highest number in the Ugandan cultivars of aromatic rice [5]. However, compared to the badh2-E7 gene, the badh2-p allele was shown to be more common in fragrant rice types in India. Both India and Japonica forms of cannabis included this gene, badh2-p. 8 bp deletion in exon 7 has been described as a functional signature of fragrant rice and is present in aromatic rice cultivars worldwide. [26]. Exon 13 in certain aromatic lines, however, exhibited a 3 bp gain rather than an 8 bp loss. Most of the described variants for the badh2 gene contain deletions and additions[27]. Seeragasamba, a short-grain aromatic rice variety similar to India, has fragrance thanks to an 8 bp insertion in the badh2 gene's promoter region. In addition, the 8 bp deletion "GATTAGGC" is followed by two significant mutation events (A to T and T to A) and is linked to scent in rice. Twenty of the 23 aromatic accessions in the research in Uganda [27] carried the badh2-E7 allele with an 8 bp deletion and three SNPs [28].

3. MOLECULAR MARKERS FOR RICE AROMA GENES

Numerous markers, including DNA and molecular markers, are used to identify QTLs in the genome. Each sort of molecular marker has advantages and disadvantages, and they are used for a variety of purposes [29]. Using molecular markers, we may rapidly and precisely identify the required trait controlled by a QTL in a single cultivar [23]" To investigate genetic variation within and among populations, as well as to identify individuals or species and trace the evolutionary history, researchers commonly employ markers such as restriction fragment length polymorphism (RFLP), random amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), inter simple sequence repeats (ISSR), simple sequence repeats (SSR), and single nucleotide polymorphisms (SNPs). However, the selection of the appropriate marker for a given study depends on the research question and the organism's characteristics, as each marker has its advantages and disadvantages [30].

4. STANDARD OF BASMATI RICE

The most crucial aspect for consumers is the flavor and scent of the rice. The demand for high-quality rice is rising in tandem with population growth [31]. A sizable portion of India's economy continues to be devoted to basmati rice. After China, India ranks as the second-largest producer of basmati rice. Basmati rice was also produced in Pakistan [32].

5. GRAIN QUALITY IMPROVEMENT

5.1 Estimation of Protein Content

With the use of a hand dehusked, seeds from 118 genotypes were dried to produce brown rice, which was then crushed to a powder for the measurement of protein content. This procedure was carried out using the micro Kedah approach. After which, the crude protein content was determined. From the chosen genotypes, 10 are high in protein, and 11 are not present in basmati [31]. The results are shown below in Fig 1 after a frequency distribution table is produced and the protein content is checked.'

5.2 Amount of Protein

Between basmati, non-basmati, and wild rice species, there were significant variances in the protein content. Comparing wild accessions to basmati and non-basmati, they have higher protein content [33].

6. GRAIN CHARACTERISTICS

6.1 Milling quality

Brown rice recovery, milled rice recovery, and head rice recovery are the variables used to evaluate quality and milling efficiency. Brown rice recovery is the proportion of brown rice that is produced after milling, reflecting the amount of grain retained and the number of nutrients it contains. Whereas recovered milled rice is the portion of white rice that was retrieved after milling, demonstrating how effectively the bran and germ were removed. While head rice recovery is the proportion of whole or fractured kernels retrieved after milling, showing the degree of grain breakage during milling. Whole grain was defined as kernels with a length more than or equal to three-quarters [34]. One of the most important milled rice parameters, head rice recovery is crucial in determining the market value of rice. The proportion of complete, intact rice grains retrieved after milling paddy rice is referred to as head rice recovery. It serves as a gauge for the effectiveness of the milling procedure and shows how many grains are fractured or otherwise damaged [35,36].

6.2 Qualitative Appearance

Appearance also plays an important role in the rice market value. The grain appearance is correlated with size shape, chalkiness, and translucency [37], Phenotype of rice is described with the help of grain length, width, and thickness. Chalkiness also affects the market value. For instance, greater chalkiness lowers the market value[38].

7. COOKING AND EATING STANDARDS

The cooking and eating quality of rice determines several characteristics, including how easily it may be prepared, how firm it remains, and how sticky it stays while consumed. The ease with which certain physicochemical characteristics, such as apparent amylose content (AAC), gel consistency, gelatinization temperature (GT), and pasting viscosity, may be assessed is directly proportional to the degree to which they correlate with the cooking and eating quality of rice [39]. The starch that constitutes up to 90% of milled rice has qualities that are connected to all of these variables. The two types of molecules that make up starch are branching amyl pectin and linear and helical amylose. I2-KI solution is used in a streamlined process to quantify amylose content.[40] Rice's amylose content, as determined by the I2-KI solution technique, is more frequently referred to as the apparent amylose content (AAC). This is because long chains of amylopectin may also bind to I2, which is why AAC is the more accurate term.

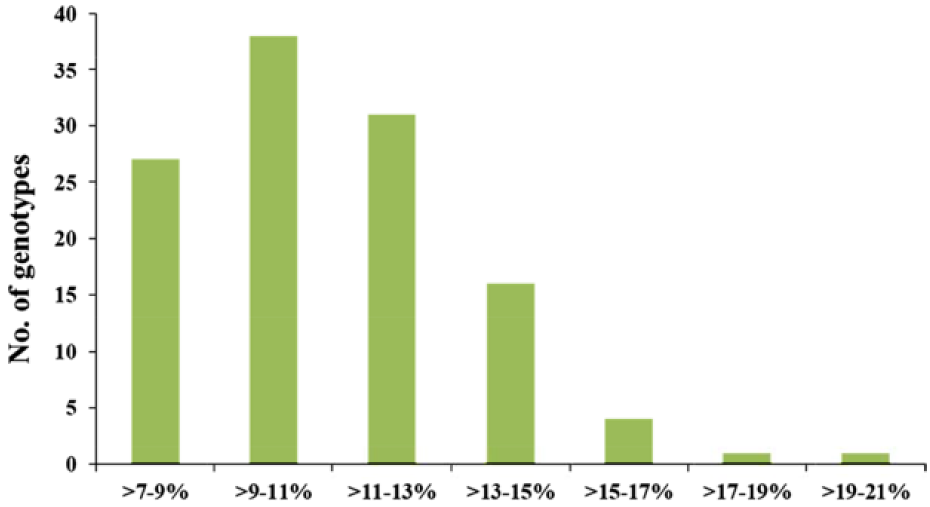

Fig. 1. Screening of genotypes based on protein content

8. NUTRITIONAL QUALITY

The Nutritional value of significant staple foods is intimately connected to people's health. Protein is the second-most prevalent component of milled rice after carbohydrates. Additionally, lysine influences the nutritional value of food [41]. In an area with low development where a lack of micronutrients is evident. The nutritional value of rice may be improved by breeding in additional micronutrients. In comparison to milled rice, brown rice offers higher minerals, vitamins, dietary fiber, and phenolic [42].

9. GENETICS AND GENOMICS OF RICE GRAIN QUALITY

The most common quality traits used to evaluate rice grain quality are milling quality, attractiveness, nutritional content, and cooking quality. Numerous genes governing quality attributes have been cloned in rice utilizing cutting-edge technologies and genomics. Numerous significant quantitative traits loci (QTLs) including qBRR-10, which improves brown rice recovery, are correlated with rice milling quality [43]. Rice grain size and shape are influenced by the genes GS3, GW5, GLW7, GW8, GS2, and GS9 [44]. Starch is crucial for maintaining the integrity of rice grains, especially those used for cooking and eating[44] [45].

10. CONCLUSION AND FUTURE PERSPECTIVE

After all review, it's concluded that aroma and grain quality alternate by the environmental effect as well as genetic effect. Aroma is a significant trait that controls the prices of variety. The gene badh2 controls the proportion of aroma. which can be improved using this gene. To further understand the variations in rice aroma's kind, strength, and stability as well as the minor genes driving it, sophisticated genomic and metabolomic methods must be used. Genomic methods involve studying the DNA sequence of rice to identify genes that are associated with aroma formation. This can be done using techniques such as genome-wide association studies (GWAS) and quantitative trait loci (QTL) analysis. These methods can identify genes that are responsible for the production of specific volatile compounds that contribute to rice aroma. Metabolomic methods involve studying the chemical composition of rice to identify the volatile compounds that contribute to aroma formation. This can be done using techniques such as gas chromatography-mass spectrometry (GC-MS) and nuclear magnetic resonance (NMR) spectroscopy. These methods can identify the specific compounds that contribute to rice aroma and help to understand the biochemical pathways involved in their production. By using both genomic and metabolomic methods, researchers can gain a more comprehensive understanding of the genetic and biochemical factors that contribute to rice aroma. This knowledge can be used to develop new rice varieties with desirable aroma characteristics and to improve the stability of aroma over time and under different storage conditions. Also, there is a need to enhance the marketing and manufacturing of short-grain aromatic rice types.

COMPETING INTERESTS

The authors have declared that no competing interests exist.

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